NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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(NASA-Case-MFS-21109-1) ERGOMETER Patent
(NASA) 8 p CSCL 06B

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REPLY TO ATTN OF: GP

TO: KSI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,744,480

Government or Corporate Employee : U.S. Government

Supplementary Corporate Source (if applicable) : ____

NASA Patent Case No. : MFS-21,109-1

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:
Yes [ ] No [X]

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words ". . . with respect to an invention of . . ."

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Enclosure
Copy of Patent cited above

United States Patent [19]

Gause et al.

[11] **3,744,480**

[45] **July 10, 1973**

[54] **ERGOMETER**

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[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration**

[22] Filed: **Nov. 29, 1971**

[21] Appl. No.: **202,769**

[52] **U.S. Cl.** .... **128/2.05 R,** 73/379, 128/2.06 R, 272/73

[51] **Int. Cl.** **A61b 5/02**

[58] **Field of Search** .... 128/2.05 R, 2.06 R, 128/2.06 F, 2.1 R, 2 R, 2 S; 272/73; 73/379

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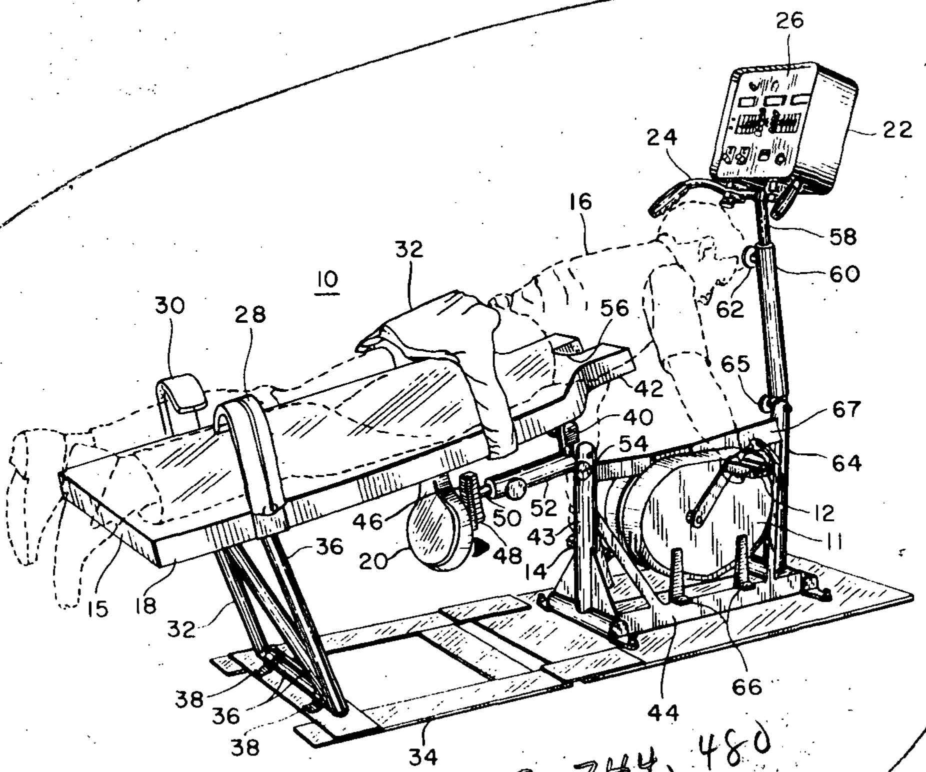
[57] **ABSTRACT**

An ergometer including a pedal driven direct current motor as a load and including a frame for supporting the body of a person in either a sitting or a prone position whereby the pedals may be operated by either the feet or the hands and the electrical circuitry of the ergometer includes means for limiting the load applied to the pedals as a function of work being performed, heart rate, and increases in heart rate.

6 Claims, 3 Drawing Figures



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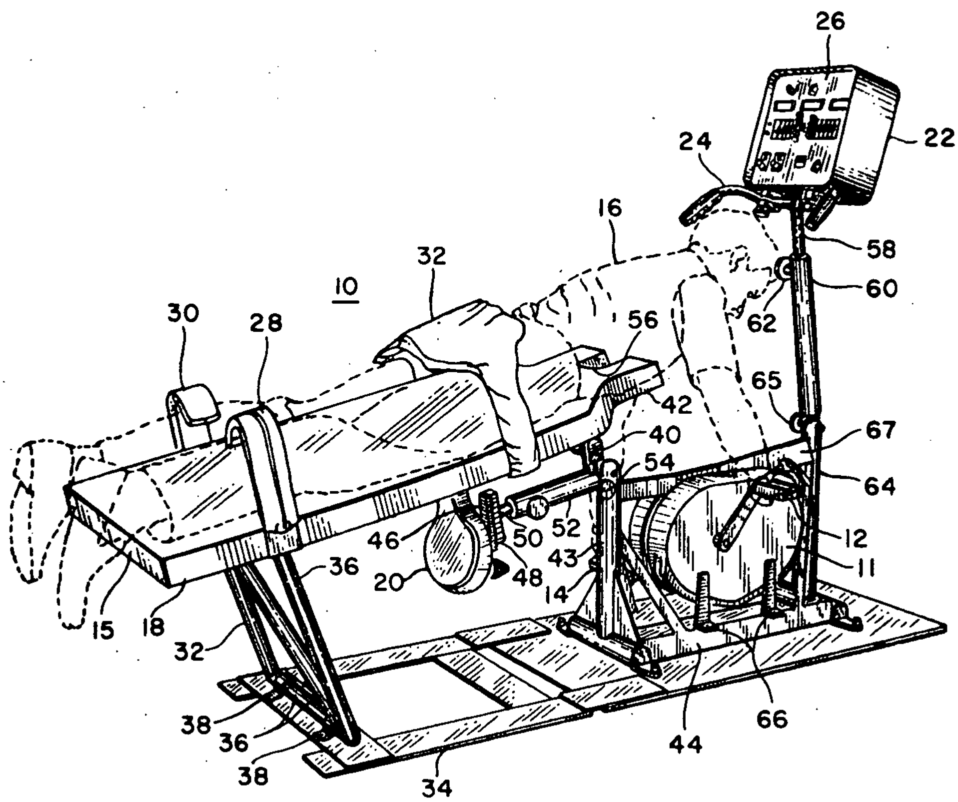

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FIG. 1

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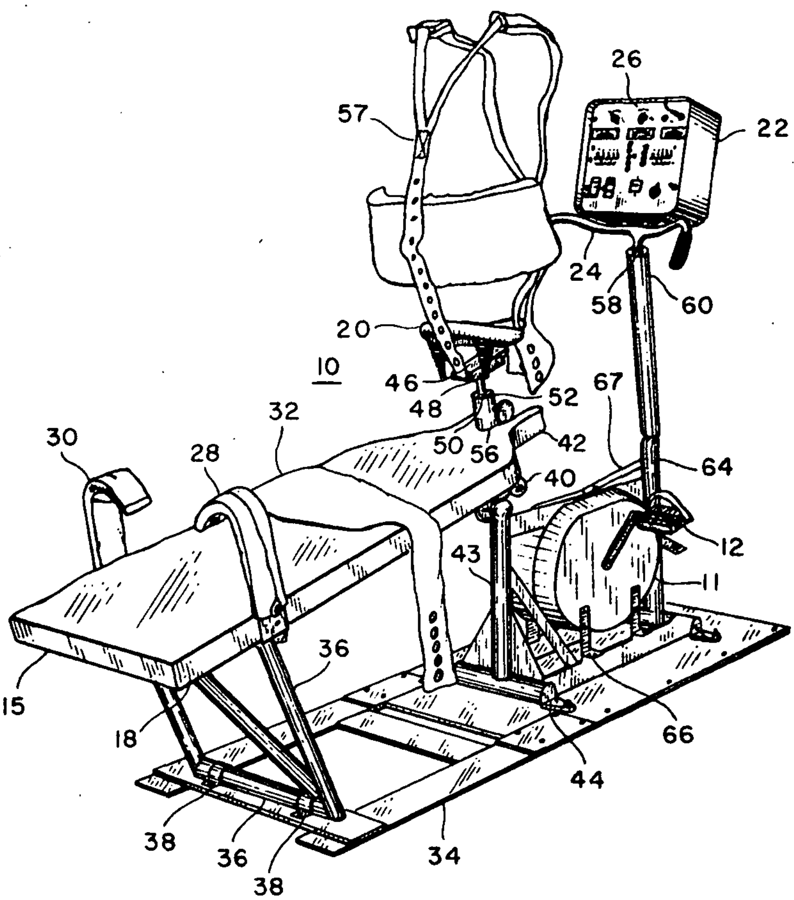

FIG. 2

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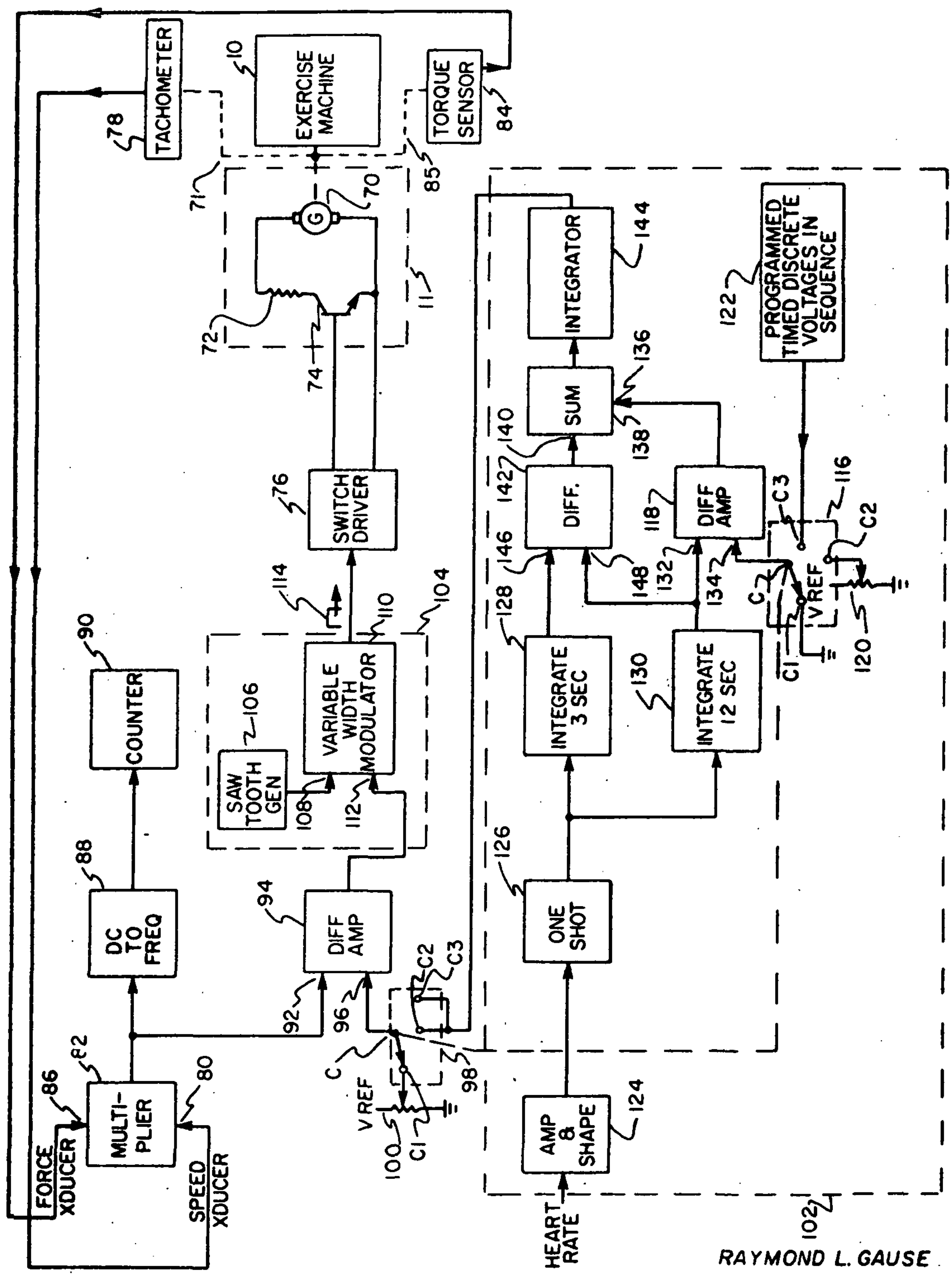

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FIG. 3

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ERGOMETER

ORIGIN OF THE INVENTION

The invention described herein was made by employees of the United States and may be manufactured and used by or for the Government of the United States of America for Governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

This invention relates generally to physiological stressing and conditioning devices and systems and more particularly to a system in which there is provided enhanced versatility in operation and more effective control of the work load imposed upon the body undergoing the conditioning.

GENERAL DESCRIPTION OF THE PRIOR ART

Devices and systems for the controlled stressing, conditioning or exercising of a person are well known. They vary from simple mechanically loaded pedal structures to sophisticated electrically regulated systems. A sometimes critical parameter in the employment of conditioning devices is the effect on the heart. Further, it is believed clear that it is generally desirable to provide some regulation of the work load as a function of heart activity.

One prior art system shows the control of work load is achieved automatically by means of a comparison of programmed work with heart rate as an indication of work and thus varying loads until the heart rate of the person being exercised equals that of the programmed work. In addition there is provided for the removal of work load in the event that a dangerous condition of the person is sensed via an ECG (electrocardiogram), temperature or chemical sensor.

One difficulty with known previous systems has been the reliance upon the exercising operator to generally regulate the speed of exercise in that actual work performed was not included as a parameter of the control system. A further difficulty has been that systems have not provided for load compensation when system inputs called for a change in loading. Thus, for example, during an increase in loading, that is between the time that increased loading is indicated and the time that it is actually achieved, excessive loading is often applied to a person. A further deficiency has existed in prior systems in that they have failed to provide versatility insofar as exercise of different limbs of the body is concerned.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a new and improved ergometer which overcomes the aforesaid difficulties.

An ergometer in accordance with the present invention includes means for comparing actual work performed with a fixed indicated work rate to be performed, and actual work rate versus the difference between a programmed heart rate and actual heart rate. As another feature of the invention there is dual integration of heart rate signals employing different time constants and the combination and a comparison made of the outputs of the two integrators to derive a work reduction signal during periods when heart rate is accelerating. A still further feature of the invention is that of employing a DC torque motor connected in a generator mode as a load source thus simplifying and providing more effective control of the load which may be accomplished simply by variable duty cycle switching of resistance connected across the terminals of the motor. A still further feature of the invention is that of an exercise frame which includes readily convertible supports enabling one to apply work by use of feet or hands.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of the exercise frame of the invention adjusted for hand operation of the pedals.

FIG. 2 is a perspective view of the exercise frame adjusted for foot operation.

FIG. 3 is a schematic illustration of the electrical system of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Considering first the physical arrangement of components, principally exercise machine **10**, reference is made to FIGS. 1 and 2. Load module **11** is driven by bicycle type pedals **12** and **14** and operator **16** may operate the pedals from either a prone position on table **18** (FIG. 1) or from a sitting position on bicycle seat **20** (FIG. 2) to react to a load effected by load module **11.** In the prone position the pedals are hand operated, as shown, and in the sitting position they are, of course, foot operated. Electronic control circuitry elements are contained in console **22** which is mounted on handlebars **24.** Front panel **26** of console **22** includes appropriate meters and controls sufficient to enable the operator to observe his performance and control the torque which he must oppose in operating load module **11.**

Table **18** (FIG. 1) is rectangular and of a dimension generally adapted to support the body of an operator from about the ankles to the chest and is typically padded for comfort. Semi- rigid leg supports **28** and **30** are attached to table **18** and adapted to vertically support the legs of the operator and belt **32** is adapted to secure the buttocks of the operator to table **18.** Table **18** is pivotally supported near end **15** by means of support assembly **32** upon flat base **34**, this assembly being constructed of round tubular members **36** which are pivotally attached to base **34** and table **18** (attachment not shown) by brackets **38** to enable table **18** to be moved backward and lowered so that seat **20** may be raised or lowered to and from an operating position. This function is enabled by coupling assembly **40** which detachably secures the other end, end **42**, of table **18** to vertical support **43** in turn supported by mounting frame **44** to base **34.**

Seat **20** is attached to plate **46** which is adjustably movable on, and attached to, supporting plate **48** to provide fore and aft adjustment of seat **20.** Supporting plate **48** is in turn supported by arm **50** which is adjustably locked in seat supporting column **52** to provide vertical adjustment of seat **20.** Column **52** is pivotally mounted on vertical support **43** by bolt assembly **54** which selectively permits column **52** to assume an operating position, as shown in FIG. 2, or a stored position, as shown in FIG. 1. In a raised or operating position, seat supporting column **52** rests against the back of recess **56** of table **18** to provide a rear lateral support for seat **20**, and the operator, when engaged in foot operation of load module **11.** Harness **57** fastened to seat **20** by means not shown further secures the operator in an operating position. Handlebars **24** are adjustably

supported in height by arm **58** supported by tubular column **60** by bolt **62.** Fore and aft adjustment of handlebars **24** is achieved by pivotal connection of column **60** to vertical support **64** by bolt assembly **65.** Vertical support **64** is in turn supported by mounting base **34** through mounting frame **44.**

Load module **11** is secured to mounting frame **44** by means of angle brackets **66** and arm **67** extending between vertical support **43** and vertical support **64.**

Considering now the control system of the invention, shown in FIG. **3,** load module **11** includes a permanent magnet torque motor **70** which functions as a generator and which is driven by pedals **12** and **14** of exercise machine **10** (FIG. **1**). Variable loading to torque motor **70** is effected by electrical resistor **72** connected across the terminals of torque motor **70** through transistor **74,** which is switched on and off in accordance with pulses of varying widths by switch driver **76.** Tachometer **78** is coupled to torque motor **70** by a shaft diagrammatically illustrated by broken line **71** and provides a speed output signal to one input, input **80,** of multiplier **82.** Torque sensor **84,** mechanically connected between torque motor **70** and its support by means diagrammatically illustrated by broken line **85,** provides a torque signal representative of the torque applied by the operator of exercise machine **10** to a second input, input **86** of multiplier **82.**

Multiplier **82** provides a direct current output representative of the rate of work being performed on exercise machine **10.** The calibration of this output by the operator is such that an output of 5 volts is representative of a work rate of 300 watts. This output is indicated or read out by first converting it to a pulse frequency proportional to voltage by DC frequency convertor **88** and then applying the thus converted output to counter **90,** which counts pulses for a predetermined period, the second being chosen to provide a direct readout of counter **90** in watts.

The output of multiplier **82** is also applied to input **92** of differential amplifier **94** and a "work demand" signal is applied to the other input, input **96,** of differential amplifier **94.** This "work demand" signal is obtained through three-position selector switch **98** in accordance with the desired mode of operation of the system. In one mode, the work rate control mode, the mode is shown by the position of movable contact *c* of switch **98** there is provided a voltage from potentiometer **100** of 0 to 5 volts, again with 5 volts being representative of a work rate of 300 watts.

"Work demand" signals which are in terms of desired heart rate are obtained in two of the three modes of operation from heart rate circuit **102** and applied to contacts C2 and C3 in a manner which will be discussed below with respect to this circuit.

In all modes of operation of the system, differential amplifier **94** provides a work demand output whenever the work demand input signal on input **96** exceeds that of the actual work signal on input **92.** The work demand output of differential amplifier **94** is applied to a variable width pulse modulator **104** which provides output pulses at a predetermined frequency but which vary in width in proportion to the amplitude of the work demand signal. Modulator **104** consists of a sawtooth generator **106** which provides a saw-tooth voltage of constant frequency to one input, input **108,** of comparator **110** and the work demand signal is applied to the other input, input **112,** resulting in a variable cut-off of the amplitude of the saw-tooth voltage and thus variable width output pulses **114** are a function of the work demand signal **112.**

The output of modulator **104** is amplified in switch driver **76** and is employed to control transistor **74** of load module **11** turning transistor **74** on during the presence of a pulse and off when no pulse is present. In this fashion transistor **74** provides control of the loading of torque motor **70,** effecting loading by closing an electrical path through resistor **72** during the presence of a pulse and closing this path in the absence of a pulse. Thus the average work extracted by load module **11** is proportional to the pulse "on-time" for the period averaged.

As stated above, two modes of operation of the system contemplate work requirement based upon heart rate. These modes are selected by positioning selector switches **98** and **116** with movable contact C in contact with fixed contacts C2 or C3. It is to be noted that switches **98** and **116** are mechanically linked for operation in unison. With the movable arm C of selector switch **116** in contact with fixed contact C2 and thus an input provided to differential amplifier **118** from potentiometer **120,** potentiometer **120** is set to a position to provide an output voltage, again in the range of 0 to 5 volts, representative of the selected heart rate of 0 to 200 beats per minute.

Alternately, with selector switch **116** set with movable contact C in contact with fixed contact C3, differential amplifier **118** is connected to the output of programmer **122.** Programmer **122** provides a plurality of selected voltages, corresponding to desired heart rate demands, which voltages are made available in a selected sequence and for selected periods. Such circuitry is believed well known and is not further described herein.

Actual heart rate signals are also provided as an input to heart rate circuit **102** to enable the limiting of work demand signals applied to input **96** of differential amplifier **94** during the period when there is a shift in the heart rate demand as called for by programmer **122** or potentiometer **120.** Thus, sudden or too rapid a change in demand is avoided by heart rate circuit **102.** This is accomplished as follows. An ECG, electrocardiogram, type signal is obtained by appropriate sensors from the body of operator **16.** This signal is amplified and shaped by amplifier and shaper **124** to obtain a pulse output from ECG waveforms, thus corresponding to heart beats and this output is applied to one shot **126** which provides output pulses, one for each heart beat, of constant amplitude and width. Heart beat pulses from one shot **126** are applied to both short (approximately 3 seconds) and long (approximately 12 seconds) time-constant integrators **128** and **130.** Long term integrator **130** provides a direct current output voltage which is continuous and proportional to heart rate. It is applied to input **132** of differential amplifier **118.** As previously indicated, a desired heart rate voltage is applied to the other input, input **134** of differential amplifier **118.** The output of differential amplifier **118,** representing the error or difference between demanded heart rate and actual (average for several seconds) heart rate is applied to input **136** of summing circuit **138.** A second input is applied to input **140** of summing circuit **138** from differential circuit **142** which provides a signal representative of the difference between the output of short time-constant integrator **128**

and long time-constant integrator **130**. The result is that the signal applied to input **140** is a signal representative of actual heart rate less a factor proportional to acceleration of heart rate or plus a factor proportional to deceleration of heart rate, as the case may be. Thus, summing circuit **138** computes a heart rate demand control signal which is the sum of the output of differential circuit **118** and differential amplifier **142** and wherein the sum would be expressed as $D_s = V_1 + V_2$ where

V_1 = a voltage proportional to actual heart rate minus desired heart rate.

V_2 = a voltage proportional to the first derivative of actual heart rate.

The output of summing circuit **138** is further integrated in integrator **144** to provide an output which averages and thus eliminates rapid changes in the "demand" signal. The sense of the "demand" signal is that of a signal which indicates that actual heart rate differs from desired heart rate and is of a magnitude to achieve a change in heart rate at a desired rate of change.

Differential amplifier **94**, with a work rate signal applied to input **92** and a heart rate "demand" signal applied to input **96** provides an applied signal to pulse width generator **104** when the inputs to terminals **92** and **96** are not identical and causes pulse generator **104** to provide control pulses to operate switch driver **76** and thus cause a change in loading to effect the loading determined by the desired heart rate demand signal.

To examine operation of the ergometer, assume first that selector switch **98** is set in the indicated position and potentiometer **100** is set to provide an output voltage of 2.5 volts, corresponding to a desired work rate of 150 watts, and this voltage is applied to input **96** of differential amplifier **94**. Prior to pedaling by the exerciser, there will be no feedback inputs to multiplier **82** and thus no input to input **92** of differential amplifier **94**. The result will be that differential amplifier **94** will respond to the full input signal on input **96** to trigger pulse generator **104** to provide relatively wide modulating pulses to switch driver **76**. It in turn will operate transistor **72** to complete a loading circuit through resistor **72** across torque motor **70** during each such pulses. Upon pedaling exercise machine **10**, tachometer **78** and torque sensor **84** provide speed and torque signals to multiplier **82**, and a product output, representative of the rate of work being performed, is applied to input **92** of differential amplifier **94** to oppose the input on input **96**. When pedaling is accelerated to the point where the actual work rate is equal to the work rate setting of potentiometer **100**, and the voltages at inputs **92** and **96** are equal, the output of differential amplifier **94** drops to zero and momentarily the pulse width output of pulse generator **104** diminishes to zero. Actually this zero pulse width condition exists only instantaneously since the result will be that there will be a like instantaneous drop in torque in the product input signal on input **86** causing a differential voltage, and thus pulsed loading of torque motor, to again occur. Thus, average loading is maintained at the work rate setting of potentiometer **100**. Load switching effects when loading is near the selected load are minimal in view of the fact that with a small difference between the load demand signal on input **96** and actual load signal on input **92** there is provided a small output signal to pulse generator **104** to produce relatively narrow switching pulses. Accordingly, change from zero pulse width to a discrete pulse width is of small magnitude.

The actual work rate as computed by multiplier **82** is indicated by counter **90** in the manner described above.

Assume next that it is desired to regulate the work request to operate exercise machine **10** in terms of desired heart rate. This is accomplished manually by the setting of potentiometer **120** to a level corresponding to heart rate for continuous loading or automatically by setting programmer **122** to provide a series of timed, discrete, heart rate voltages. Assuming that it is desired to operate the ergometer in the first of these two modes of operation, selector switch **116** is positioned with movable contact C in contact with fixed contact C2. Potentiometer **120** is then set to a preselected heart rate analog voltage of said 2.5 volts representative of 100 beats per minute and the voltage is applied to input **134** of differential amplifier **118**. Assume further that the operator of ergometer **10** is pedaling and that his initial heart rate is 80 beats per minute and thus less than the desired heart rate. An actual heart rate signal is derived, as described above, by processing an ECG signal through amplifier and shaper **124** and one-shot **126** to provide pulse inputs to integrators **128** and **130** of a predetermined height and width.

Since the desired heart rate is significantly higher than the actual heart rate there is a requirement that there be a substantial increase in loading on the exerciser. On the other hand, as discussed above, it is not desirable to increase the loading, this heart rate, too rapidly. To prevent this, operation of circuitry is as follows. One set of the heart rate pulses are integrated by short time-constant integrator **128** to provide a direct current output to input **146** of differential circuit **142** which is a direct current but which with change in rate takes the form of stair steps, ascending or descending, depending upon whether there is an increase or decrease in heart rate. A second set of the heart rate pulses are subject to long time-constant integration in long time-constant integrator **130** and the resulting output reflects the generally long term average heart rate which is fed to input **132** of differential circuit **118** and to input **148** of differential amplifier **142**. The output of differential circuit **142** is thus a signal which may be characterized as of a value proportional to average heart rate less a value proportional to increasing heart rate, or plus a value proportional to decreasing heart rate. The output of differential amplifier **118** is simply an error signal indicating the difference between desired heart rate and average heart rate, or required change in heart rate. The outputs of differential circuit **142** and differential circuit **118** are summed in summing circuit **138** to provide an output which is proportional to the difference in actual heart rate and desired heart rate and the rate of change of actual heart rate. The output of summing circuit **138** is integrated by integrator **144** to accomplish the smoothing of the signal to provide a gradual rather than stepped changes in the signal during heart rate changes. The result is that there is a demand signal from integrator **144** which is applied to input **96** of differential amplifier **94** which is of a desired value to produce the desired rate of increase in heart rate at a desired characteristic of increase and without abrupt changes in demand. The operation of differential amplifier **94** and the balance of the loading circuitry is the same as described above for the application of a load demand signal from potentiometer **100**.

Thus loading is increased in accordance with the value of the signal on input **96** of differential amplifier **94**, with feedback signals from speed tachometer **78** and torque sensor **84**, respectively, to multiplier **82** limiting the force application to that described by the input signal on input **96** of differential amplifier **94**.

In the programmed mode of operation, with movable contact C in contact with fixed contact C3, a series of programmed voltages are applied to input **134** of differential amplifier **118** for predetermined periods. Otherwise, the operation of heart rate circuitry **102** and load circuitry is identical to that just described.

What is claimed is:

1. An ergometer comprising:
   - exercise means adapted to be operated by limbs of the body and providing a mechanical output;
   - electrical load means connected to the said output of said exercise means for applying resistance to the operation of said exercise means;
   - load control means responsive to an input signal for varying said resistance applied to said exercise means;
   - work signal means responsive to the speed of operation of said exercise means and resistance force applied to said exercise means for providing a work output signal;
   - physiological monitoring means responsive to a condition of an operator of said exercise means for providing an electrical output corresponding to heart beats of said operator;
   - first and second integrating means responsive to the output of said physiological monitoring means, said first integrating means having a longer time constant than said second integration means;
   - first differential means responsive to the outputs of said first and second integrating means for providing a first difference signal of a value proportional to actual heart rate less a value proportional to increasing heart rate, or plus a value proportional to decrease in heart rate;
   - heart rate signal reference means for providing an output representative of a desired heart rate from said operator;
   - second differential means responsive to the outputs of said first integrating means and said heart rate signal means for providing an output corresponding to an error signal indicating the difference between desired heart rate and actual heart rate of said operator;
   - summing means responsive to the outputs of said first and second differential means for providing a heart rate demand signal which is proportional to required change in heart rate to achieve said desired heart rate less a value proportional to the presence of increasing heart rate or plus a value proportional to the presence of decreasing heart rate; and
   - third differential means responsive to the output of said work signal means and said summing means for providing said input signal to said load control means;
   - whereby a work rate imposed upon an operator of said exercise means is determined by a desired heart rate activity of the operator as modified by rate of change of heart rate experienced by the operator during an imposed change from one heart rate to another.

2. An ergometer as set forth in claim **1** further comprising a work rate signal reference means and selection means for coupling either said heart rate demand signal or the output of said work rate signal reference means to said third differential means,
   - whereby said load control means may, selectively, be controlled as either a function of a selected work rate or a selected heart rate.

3. An ergometer as set forth in claim **2** wherein said heart rate signal reference means includes programming means for selectively applying in sequence, predetermined, discrete said outputs for predetermined periods of time.

4. An ergometer as set forth in claim **1** wherein said load control means includes pulse width modulation means responsive to the output of said third differential means for generating variable width control signals proportional to the output of said third differential means for controlling said electrical load means.

5. An ergometer as set forth in claim **4** wherein said pulse modulation means comprises:
   - a comparator,
   - a saw-tooth oscillator operating at a predetermined frequency and providing a first input to said comparator;
   - said third differential amplifier provides a second input to said comparator,
   - whereby said variable width pulses are obtained by coincidence of signal levels between said saw-tooth oscillator and said output of said third differential amplifier.

6. An ergometer as set forth in claim **4** further comprising integration means coupling said summing means to said third differential means for smoothing the coupled signal to provide gradual rather than step changes in the coupled signal during heart rate changes.

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